

Upper Pennsylvanian Steubenville Coal-Ball Flora¹

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ABSTRACT. The Upper Pennsylvanian (Conemaugh Group) Duquesne Coal west of Steubenville, Ohio represents a deltaic peat-accumulating swamp, and is one of the best known of coal swamp floras. In a few places, the peat was infiltrated and permineralized by calcium carbonate prior to coalification, thus producing coal balls in which both morphological and anatomical structure of the constituent plant parts are preserved. The plant material represents primarily the community that inhabited the peat-accumulating environment, but some remains from near-swamp environments also are represented. The flora is relatively diverse, consisting of over 55 megafossil taxa of isolated organs that were produced by at least 25 species of plants. All five major groups of Pennsylvanian coal-swamp plants (i.e., Lycopsidea, Sphenopsida, Pteridopsida, Pteridospermopsida and Cordaitales) are represented.

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INTRODUCTION

Coal balls were discovered in the Upper Pennsylvanian Duquesne and Ames coals west of Steubenville, Ohio in the summer of 1975, and were reported the following year (Rothwell 1976). Those from the Duquesne Coal contain some of the best preserved coal-ball permineralizations, and the fossils are now among the most extensively studied of late Paleozoic plants. Plant remains from the Ames Coal are not as well preserved, but appear to represent a comparable flora.

The Duquesne and Ames coal seams crop out in a road cut on the south side of U.S. 22 approximately 7 km west of the west corporation boundary of Steubenville (14.6 km on U.S. 22 west of the Steubenville bridge across the Ohio River). This area is locally known as Reed's Mill Hill; the coal seams apparently were exposed when U.S. 22 was widened in about 1970. Neither coal seam is well developed or extensive. The Duquesne Coal and, in places, the Ames Coal (Rothwell 1976) are represented primarily by unconformities on the north side of the highway. The Ames Coal occurs directly below the Ames Limestone, and usually is covered by talus. Above the Ames Limestone are silty beds with enclosed dolomitic(?) concretions. Near the top of these silty beds there are crevasse splay sands of varying thicknesses and some evidence of local unconformities. The underclay of the Duquesne Coal is poorly developed in this area.

The Duquesne Coal was derived from organic material deposited in a Late Pennsylvanian, deltaic peat-accumulating swamp. It crops out for a distance of approximately 140 m and is topped by an unconformity. To the west the coal is truncated by the unconformity; to the east there is evidence that the coal was rafted. The coal is overlain by a thick cap of coarse, cross-bedded sandstone with numerous unconformities. In addition to the rafted coal at the east end of the exposure, there are coalified remains of plant debris and impressions in the sandstone. The impressions consist primarily of large fragments of unidentifiable wood and bark detritus, with occasional impressions of *Sigillaria* and *Calamites* stems. The Duquesne Coal at this exposure is up to 38 cm thick, and is split by a sandstone parting to the west. Coal balls occur sporadically along the exposure. In some areas they

occur in a single, *in situ* layer at the bottom of the seam, but in other areas they replace the coal and the thickness of the bed expands to over 1 m. In the latter areas, the coal balls often have rounded edges, are positioned with the bedding plane of the plants at random, and are separated by both coal and some clastic material. Although considered unlikely by some geologists, these latter coal balls may have been formed elsewhere in the Duquesne Coal peat, transported as cobbles, and redeposited in channels within the peat before deposition of the overlying sandstone.

FLORISTICS

The five major permineralized taxa of Pennsylvanian coal swamps (i.e., lycophytes, sphenopsids, ferns, seed ferns, and cordaites) are all well represented in the flora of the Duquesne Coal, and now are known much better than when the preliminary floristic list was compiled (Rothwell 1976). The information summarized in this report is derived from earlier studies of individual plants (see Literature Cited) as well as from previously unpublished observations. Most of the plant debris is interpreted as remains of the community that grew in the peat-accumulating swamp. However, the lycophyte, *Sigillaria*, and the cordaites, *Mesoxylon priapi*, are interpreted as inhabitants of near-swamp environments (Trivett and Rothwell 1985).

LYCOPHYTES. Lycophytes consist of four plants. These are 1) the small *Selaginella*-like heterosporous *Paurodendron fraipontii* (Rothwell and Erwin 1985); 2) the unbranched heterosporous *Chaloneria cormosa* (Fig. 1; Pigg and Rothwell 1979, 1983a, 1983b, 1985); and 3) at least two species of the arborescent *Sigillaria*. Although the stems (*Sigillaria*), leaves (*Sigillariophyllum*), and rooting organ (*Stigmara*) have not been studied in detail, two species of megasporangiate cones, (*Mazocarpon villosum*, Fig. 3, and *M. bensonii*; Pigg 1983) and one species of microsporangiate cone (*M. bensonii*, Fig. 2; Feng and Rothwell 1987) have been described.

SPHENOPSIDS. Both sphenophyllalean and calamitalean sphenopsids occur in the Duquesne Coal, but only one species of cone (Riggs and Rothwell 1985) has been studied in detail. The sphenophyllales consist of

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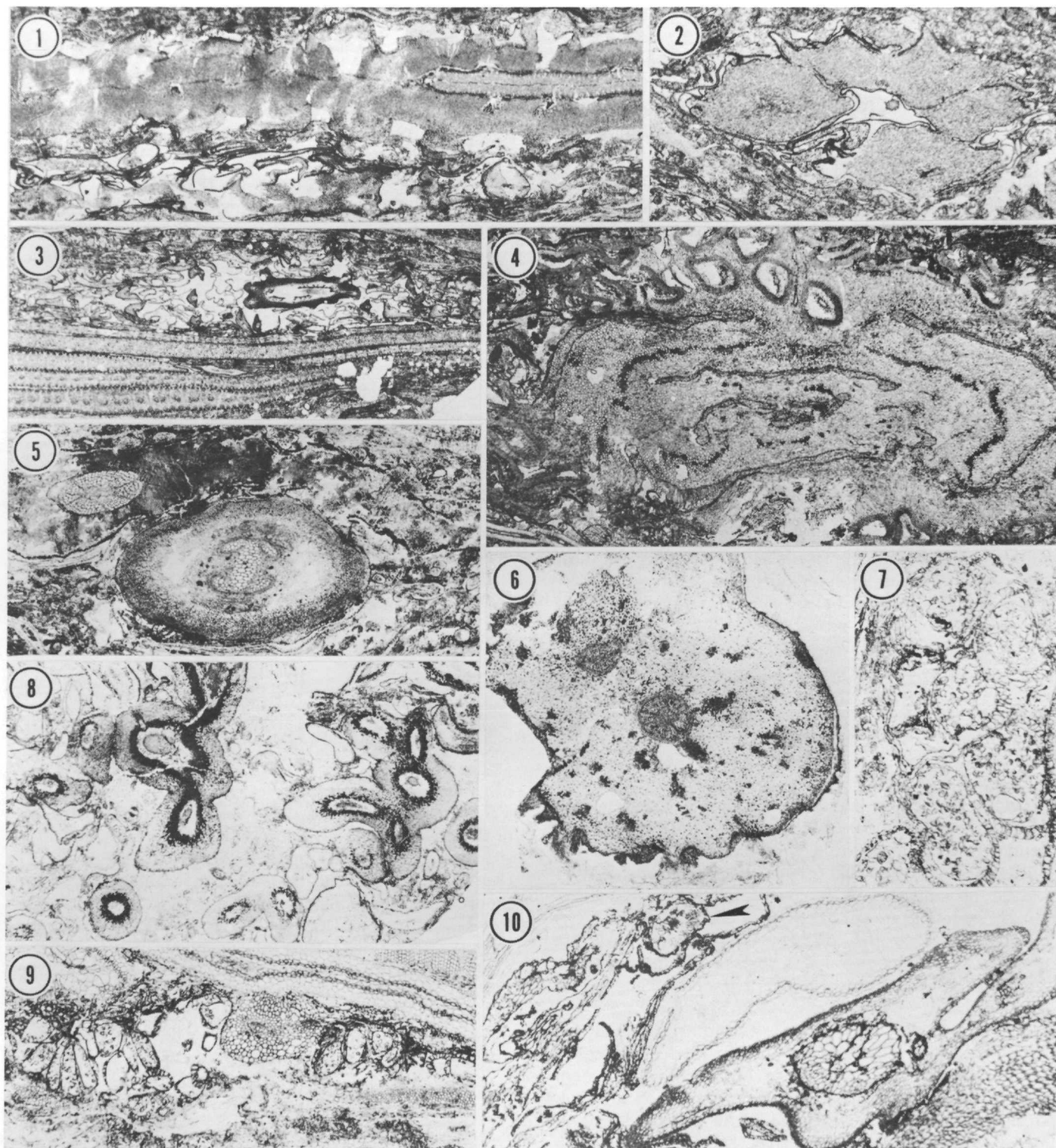


FIGURE 1. Flattened stem of *Chaloneria cormosa* in cross section. O.U. Coal Ball 1352 F Bot. #92 \times 2.5. Fig. 2. Microsporangiate cone of *Mazocarpon bensonii* in cross section. O.U. Coal Ball 1416 C₍₁₎ Side. #145 \times 5. Fig. 3. Megasporangiate cone of *Mazocarpon villosum* in oblique cross section (at top), and *Cordaites felicitis*-type leaves of *Mesoxylon priapii* in cross section (at bottom). Ohio University Paleobotanical Herbarium (O.U.P.H.) #92 \times 4. Fig. 4. Relatively young stem of *Psaronius blicklei* sp. in cross section. Note "bound" adventitious roots at top. O.U. Coal Ball 1609 D Bot. #68 \times 2.5. Fig. 5. Zygoterid petiole, *Eptopteris scottii*, in cross section, with cross section of the stem, *Zygoteris* sp. at upper left. O.U. Coal Ball 2077 E Top. #11 \times 5. Fig. 6. *Zygoteris illinoensis* stem in cross section, with petiole trace toward upper left. O.U. Coal Ball 1289 J Top. #18 \times 4. Fig. 7. Cross section of a sorus of *Corynepteris involucreta*, showing several sporangia with enclosed spores. O.U. Coal Ball 1413 D Top. #2 \times 25. Fig. 8. *Botryopteris forensis* epiphyte growing within the aerial roots of *Psaronius*. Two stems in cross section, each producing petioles and branches. O.U. Coal Ball 2911 B₍₂₎ Top. #4 \times 2.5. Fig. 9. Cross section of a fertile pinnule of *Doneggia complura*, showing midrib at center and a large sorus of abaxially attached sporangia to each side. O.U. Coal Ball 552 E Top. #15 \times 15. Fig. 10. Filicalean fern with indusiate sporangia (at arrow) and *Anachoropteris clavata*-type pinna-trace anatomy (at lower right). O.U. Coal Ball 442 B Top. #9 \times 20.

stems, roots, and leaves of *Sphenophyllum* and the cone *Sentistrobis goodii* (Riggs and Rothwell 1985). Calamitaceans consist of stems, *Asterophyllites*-type leaves,

megasporangiate cones of *Calamocarpon*, and microsporangiate(?) cones of the *Calamostachys*-type that probably also represent *Calamocarpon*.

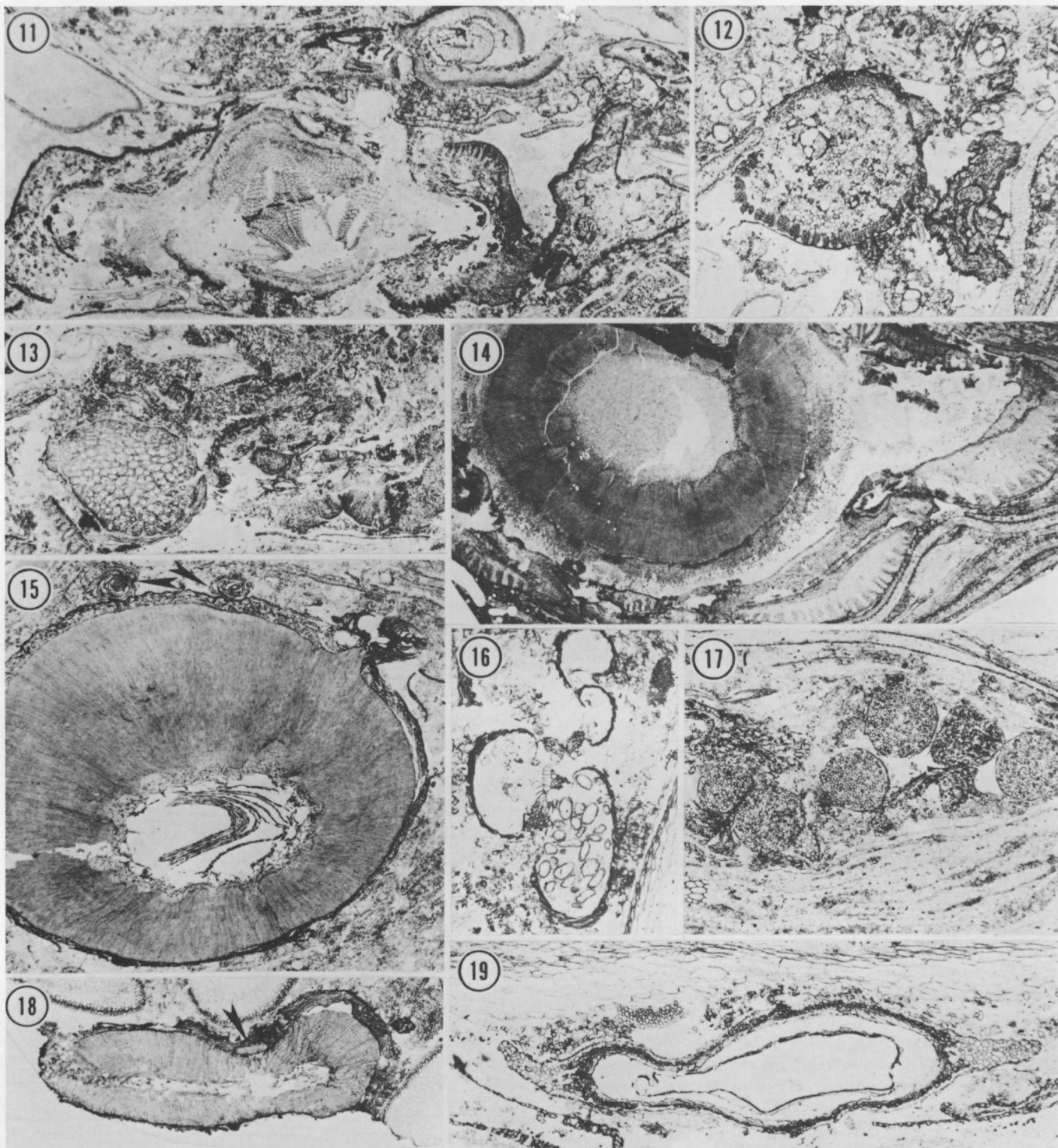


FIGURE 11. Cross section of *Medullosa endocentrica* stem with petiole at right. Note also cross section of the pinna *Anachoropteris* sp. at top. O.U. Coal Ball 928 C₂ Top. #23 × 4. Fig. 12. Cross sections of medullosan pinna, *Myeloxylon* (at center), young stem of *Callistophyton poroxylloides* (at right), and *Scolecopteris* sp. synangia. Note the absence of secondary tissues at this level of *Callistophyton*, and that the *Scolecopteris* synangia typically are constructed of four sporangia each. O.U.P.H. #104 × 9. Fig. 13. Cross section of *Heterangium* sp., with the stele of a protostelic stem at left and a petiole with several traces at right. O.U.P.H. #108 × 5. Fig. 14. Cross section of *Mesoxylon priapii* stem with parenchymatous pith and prominent leaf bases (at lower right). Note also more distal cross sections of leaves at lower right. O.U. Coal Ball 1398 A Bot. #3 × 2.5. Fig. 15. Cross section of *Cordaixylon dumusum* stem with septate pith and much narrower cortex than the *Mesoxylon priapii* stem in Fig. 14. Note attached bud (at upper right) and two sections of *Cordaitanthus*-type cones (at arrows). O.U. Coal Ball 1604 F Bot. #72 × 4. Fig. 16. Cross section of *Rhetinotheca patens* pollen organ, showing the four sporangia that characterize this species. Note also *Monoletes*-type prepollen in lower sporangium. O.U. 1757 C Bot. #6a × 25. Fig. 17. Several distal sporangia of *Phyllipteris globiformis*, each filled with spores. O.U. 1413 C Top, a. #126 × 15. Fig. 18. Flattened stem of *Cyathotheca ventilaria* in cross section. Note abundant wood and simple leaf tract (at arrow). O.U. Coal Ball 1213 K Top, b. #11 × 9. Fig. 19. Cross section of *Mitrospermum vinculum* at mid-level, showing prominent wings. O.U. 552 F Bot. #6 × 25.

FERNS. Marattiaceous tree ferns, zygopterid ferns, and small filicaleans (previously assigned to Coenopteridales) are prominent in the assemblage. The

marattiaceous remains make up the bulk of the debris, comprising approximately 45% (by volume) of the Duquesne Coal peat (Pryor 1987b). These include stems

of *Psaronius chasei* and *P. blicklei* (Fig. 4; Mickel 1984), and frond fragments assignable to *Stipitopteris* and *Pecopteris*. There also are several species of fertile psaroniacean foliage (Fig. 12), including *Scolecopteris charma* (Lesnikowska and Millay 1985), but the largest volume of psaroniacean debris consists of aerial roots of *Psaronius*.

Two species of zygopterid ferns have been identified in the Duquesne Coal. Both have stems assignable to *Zygopteris* (Fig. 5); isolated stem fragments conform to both *Z. illinoensis* (Fig. 6) and *Z. berryvillensis*. One species of fertile structures conforms to *Biscalitheca musata* (Millay and Rothwell 1983); the other is identified as *Corynepteris involucreta* (Fig. 7; Trivett 1986). Both species have petioles assignable to *Etapteris* (Fig. 5).

Filiclean ferns have petiole traces assignable to *Botryopteris* and *Anachoropteris* (Fig. 11). The *Botryopteris forensis* plant recently has been identified as an epiphyte on trunks of *Psaronius* (Fig. 8). Another plant with petiole traces assignable to *Anachoropteris clavata* (Fig. 10) was a vine with indeterminate growth of the frond and many features that characterize modern ferns (Rothwell 1987, Trivett 1987).

The most common frond parts compare closely with *Anachoropteris involuta*, and were borne on stems assignable to *Tubicaulis*. Fertile parts of these ferns are known as *Donegia complura* (Fig. 9; Rothwell 1978) and *Sermaya* sp.

SEED FERNS. Seed fern remains are assignable to the Lyginopteridaceae, Medullosaceae, and Callistophytaceae. Lyginopterids include stems and fronds of *Heterangium* (Fig. 13), and the ovules of *Conostoma platyspermum* (Rothwell et al. 1979) and *C. quadratum*. *Callistophyton poroxyloides* (Fig. 12), with pollen organs of *Idanotbekion callistophytoides*, and ovules of *Callospermion pusillum* (Rothwell 1981) represent the Callistophytales.

There are at least four medullosan plants in the Duquesne Coal. One is the relatively small vine, *Medullosa endocentrica* (Fig. 11; Hamer and Rothwell 1987); the other three all have stems assignable to *M. noei* (Beeler 1983, Pryor 1987a). Two of the plants have fronds with *Myeloxylon* pinnae (Fig. 12) and *Neuropteris* pinnules (i.e., *N. ovata* and *N. scheuchzeri*; Beeler 1983). The third has *Myeloxylon* pinnae and *Alethopteris* pinnules (Mickle and Rothwell 1982, Pryor 1987a). Fertile structures have not been found attached to the vegetative remains, but there are four types each of ovules and pollen organs. These are *Pachytesta stewartii*, *P. illinoensis*, *P. berryvillensis* and *Hexapterospermum* sp. ovules, and *Bernaultia formosa*, *Rhetinotrocha patens* (Fig. 16), *Halletheca reticulatus* and cf. *Rhetinotrocha* sp. pollen organs (Rothwell and Mickle 1982, Rothwell and Eggert 1986, Hamer and Rothwell 1987, Pryor 1987b).

CORDAITALEANS. Cordaitaleans are represented by two plants. One is the small shrub *Cordaixylon dumusum* (Fig. 15; Rothwell and Warner 1984). When isolated, the ovules of this plant are known as *Cardiocarpus oviformis*, the ovulate cones are *Cordaitanthus duquesnensis* (Rothwell 1982), and the pollen is assignable to *Florinites* (Rothwell 1982). The second plant is *Mesoxylon priapi* (Fig. 14; Trivett and Rothwell 1985). It has cones of the *Gothania*-type, leaves that are similar to *Cordaites felices* (Figs. 3, 14), and prepollen assignable to *Sullisaccites*. This species is associated with *Mitrospermum vinculum*

ovules (Fig. 19; Grove and Rothwell 1980, Trivett and Rothwell 1985).

PLANTS OF UNCERTAIN AFFINITIES. There also are several plants of uncertain affinities within the Duquesne Coal. One is the sporangial fructification, *Phillipopteris globiformis* (Fig. 17; with *Dictyotrilites*-type spores; Hamer and Rothwell 1983). Another plant has woody stems, pinnately-lobed leaves, and unusual sporangial fructifications. This second species, *Cyatbotheca ventilaria* (Fig. 18; Mickle and Rothwell 1986), combines features typically associated with both ferns and seed plants.

DISCUSSION

The flora of the Duquesne Coal currently is one of the most completely understood of all Paleozoic plant assemblages. This is due, in part, to the abundance and excellent preservation of the fossils. However, it also is due to a broadening of the approach that is employed in the study of permineralized plants. Until recently, permineralized plant remains (and plant remains in general) were studied primarily as isolated organs that were sometimes grouped into assemblages to provide a generalized impression of what a representative of each major group may have been like.

For over 100 years this methodology has provided general impressions of fossil floras, but it lacks the specificity necessary to explore species diversity and reconstruct community physiognomy. It also provides little information for interpreting floristic patterns and paleoecology. By expanding our approach to include whole plant reconstructions based primarily on interconnected organs (Beeler 1983, Hamer and Rothwell 1987, Pigg and Rothwell 1983a, 1983b, Pryor 1987a, Rothwell and Warner 1984, Trivett and Rothwell 1985) and by employing quantitative floristic analysis (Pryor 1987b), we now are beginning to reconstruct the fossil vegetation as a mosaic of dynamic communities. This has enhanced dramatically our understanding of the vegetation that produced the Steubenville assemblage, and is an encouraging indication of the utility of the broadened approach.

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